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Effect of Tactile Feedback on Performance

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TACTILE FEEDBACK ON PERFORMANCE

by

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ABSTRACT

Humans interact with their environment by obtaining information from various modalities of sensing. These various modalities of sensing combine to facilitate manipulation and interaction with objects and the environment. The way humans interact with computers mirrors this environmental interaction with the absence of feedback from the tactile channel. The majority of computer operation is completed visually because currently, the primary feedback humans receive from computers is through the eyes. This strong dependence on the visual modality can cause visual fatigue and fixation on displays, resulting in errors and a decrease in performance. Distributing tasks and information across sensory modalities could possibly solve this problem. This study added tactile feedback to the human computer interface through vibration of a mouse to more accurately reflect a human's multi-sensory interaction with their environment. This investigation used time off target to measure performance in a pursuit-tracking task. The independent variables were type of feedback with two levels, (i.e., tactile feedback vs no tactile feedback) and speed of target at three different levels, (i.e., slow, medium, and fast). Tactile feedback improved pursuit-tracking performance by 6%. Significant main effects where found for both the speed and feedback factors, but no significant interaction between speed and feedback was obtained. This improvement in performance was consistent with previous research, and lends further support to the advantages multi-modal feedback may have to offer man-machine interfaces.

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INTRODUCTION

Today, more than ever, computers are part of our everyday lives. The way we interact with computers is evolving, but continues to be somewhat limited in modes of feedback at its interface. Maximizing the performance, usability, efficiency, and effectiveness of human-computer interfaces has become top priority for new systems trying to find a place in today's rapidly evolving marketplace. Humans interact with their environment by obtaining information from various modalities of sensing. These various modalities of sensing, primarily visual, auditory, and tactile, combine to facilitate manipulation and interaction with objects and the environment. However, the human computer interface is limited in the availability of sensory modalities. The mouse, monitor and keyboard have become the standard interface between humans and computers, and the modes of feedback that are utilized have been primarily focused on the visual modality with limited audio. The limited auditory stimuli are usually reserved to signal an error or the completion of an operation. This means that the majority of operation is completed visually because the only feedback from the computer is received through the eyes (Fukui & Shimojo, 1992).

Statement of the Problem

This strong dependence on the visual modality can cause visual fatigue and fixation on displays, resulting in errors in concurrent tasks or in the primary task. This situation may be improved by incorporating feedback from other senses. In the current configuration, the keyboard and mouse are already being used to transmit information from the human to the computer, but they are not being utilized to transmit information from the computer to the human (Figure 1). The most widely used input device today is the mouse. The mechanisms required to convey tactile information to the human are inexpensive to manufacture. Advances in miniaturization and fine tune controlling of frequency, magnitude, and duration in haptic devices, has made them more practical and acceptable in operational settings. This could also mean that the easiest and most economical sense to incorporate is the sense of touch. With half of the loop already in place, it makes sense to take advantage of the resources that are already there (Figure 1).

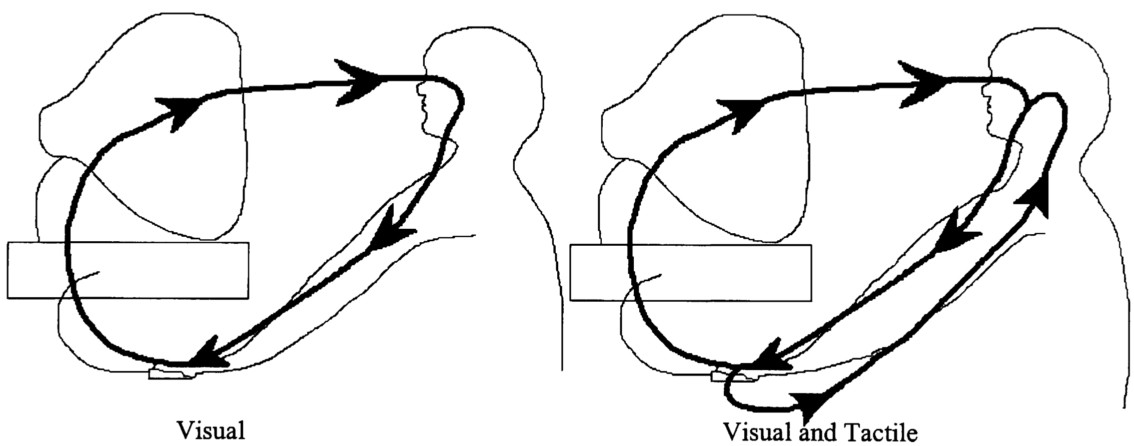

Figure 1. Information Flow of Feedback (adapted from Fukui & Shimojo, 1992).

To help answer the question of how the addition of tactile feedback would benefit performance, this study will address topics including, information processing, multiple resource theory, tactile feedback, the importance of immediate feedback, manual control theory, and tracking. Using a mouse to combine immediate tactile feedback with the other modes of feedback that are currently implemented in the human computer interface, would also be highly beneficial because of the way humans process information.

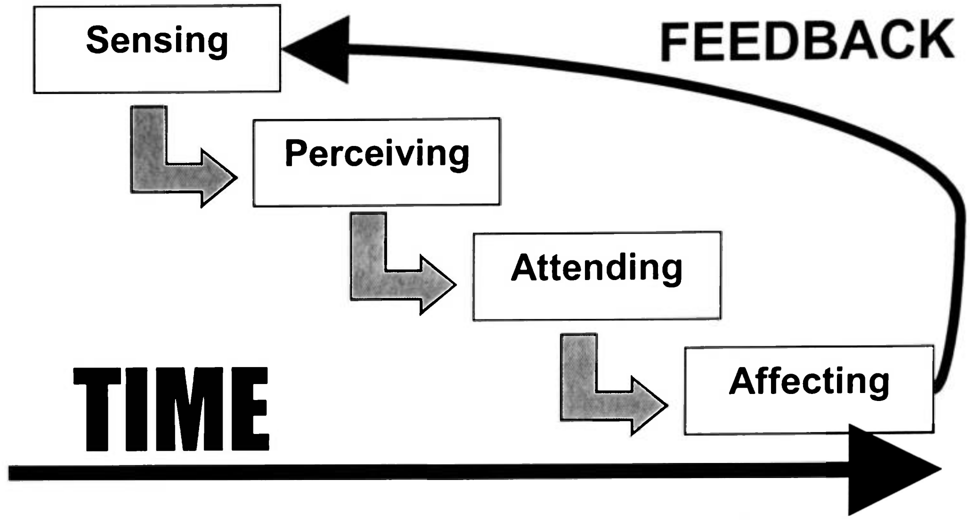

Figure 2. Information Processing Model - an illustration of the flow of cognitive processing of information from the onset of a stimulus to the observed response.

Review of the Literature

Information Processing: Human information processing has been extensively studied, and its main components consist of a loop that contains sensing, perceiving, attending and affecting all over time (Figure 2). Sensing can be defined as the process of receiving information from the environment and changing that input into nervous system activity. Information from the environment is gathered from senses including the visual, auditory, tactile, gustatory, vestibular, and olfactory. Perceiving can be defined as the cognitive process of selecting, organizing, and interpreting of stimuli. It can be a complex, active, and even a creative cognitive process. Perception of reality is not only based on the information provided by our senses, but also takes into account motivational state, emotion, expectations, and past experiences. Attending can be defined as the cognitive function where actual decision-making occurs based on sensation and perception. Perceiving and attending make up the time between signal detection and the observed behavior or response. Attending can also be focused inward toward our own thoughts, and humans are even capable of concentrating so heavily that they can be almost oblivious to external stimuli. Affecting can be defined as the response to, or observed behavior resulting from sensing, perceiving, and attending. After any decision is made, affecting is where the acting on that decision occurs. In a system concept it would be an extremely versatile output or the transmitting of information to executing physical responses. This response is also the only way to confirm that a person has received and processed information correctly. Information processing then loops back to sensing, incorporating feedback from the previous cycle.

Multiple Resource Theory: Multiple resource theory suggests that different modes of information transfer (via the different senses) represent different attentional resources, and parallel processing of information, accomplished by distributing presentation of information across modalities, can be more efficient than using a single mode of presentation (Wickens, 1980). It also states that if the demands on one of two tasks with the same resource requirements is increased (via an increase in task difficulty) the other task sharing the same resource requirements will show a greater decrease in performance than tasks with different resource requirements. Distributing information across the different modes of sensing can also account for individual differences in personal preferences and learning style between people. If the feedback is presented over multiple modes, people will have the advantages the different modes have to offer, and gain more or less from whatever they respond to best. This redundant information about the handling of on screen objects will allow a more intuitive interaction, and therefore increase task performance and decrease human workload (Göbel, Luczak, Springer, Hedicke, & Rotting, 1995). In a combat aircraft for example, the resources required in the concurrent tasks of flying and trying to lock onto a target overlap. This overlapping in required modes of input and output, increase time-sharing efficiency (Wickens, Sandry, & Vidulich, 1983). This means that multi-modal feedback, such as tactile and visual, should reduce the visual load in interactive systems, and the competition for processing resources. This will result in a positive effect on the efficiency of information processing and subsequent performance (Akamatsu, 1994). The more patterns and cues that can be linked with actions of completing a task successfully, the better they will be recalled, and the more efficiently the information will be retrieved. The more modes of feedback that are offered, the more opportunities an individual will have to link patterns and cues with a task. This learning and skill development then becomes more automatic and reduces the attentional demands required (Sanders & McCormick, 1993). Redundant and multi-modal cues could be especially useful in applications that primarily rely on one mode of information transfer, such as aviation, where visio-spatial feedback is relied on heavily. In aviation the visual mode of feedback is not well suited for capturing attention in case of unexpected changes in events or for supporting the parallel processing of large amounts of data in complex domains (Sklar & Sarter, 1999).

Another important concept to review when discussing the application of multimodal feedback to system design, is that of stimulus-response compatibility. Fitts (1954) identified stimulus-response compatibility as a key influence in information processing. His research concluded that when considering speed and accuracy of reaction time, auditory information is best responded to verbally, while visual information is best responded to manually. This stimulus-response compatibility is the rationale for much of tactile feedback research. Akamatsu, MacKenzie, and Hasbroucq (1995) also found evidence that stimulus-response compatibility contributes to quicker motor responses. Appropriate sensory modalities of interaction and the compatibility of different kinds of sensory feedback has also been expanded (Wickens et al., 1983; Baecker, Grudin, Buxton, & Greenberg, 1995: chapter 7). From these studies it seems that compatibility is found wherever there are real world analogous tasks in which sensory modes are combined. For example, a pointing task with a mouse is analogous to a reaching task with a finger (Akamatsu & Sato, 1994). When using a mouse, cursor movements follow from hand motion in a two-dimensional space known as the desktop. When a cursor or virtual hand comes in contact with something the most correct way to convey this sense is through a tactile sensation in the controlling limb (Akamatsu et al., 1995). This means that the addition of tactile feedback to the human computer interface would more closely approximate manual control of real objects.

Tactile Feedback: The two senses that are dealt with in this experiment are the visual sense and the tactile sense. These two senses have important physiological similarities and perceptual parallels. The skin and the retina contain a number of different receptors and have center-surround receptive fields. Both senses can also create the experience of apparent movement and the data reported from studies on visual and tactile sensing in this area is almost exactly the same (Goldstein, 1999). The visual sense is the primary source of performance feedback, and there is evidence that it might even have some control over motor responses on an unconscious level (Sanders & McCormick, 1993). The sense of touch originates in the bottom layer of the skin called the dermis. The dermis is filled with many nerve endings, which give valuable information about the surrounding environment. That information is then carried to the spinal cord and sent to the brain where the sensation is registered. One reason why people who are blind use their fingertips to read braille by feeling the patterns of raised dots on paper, is because there are approximately 100 touch receptors in each fingertip. The high concentration of tactile receptors in the fingertip area greatly enhances the individuals' sensation.

> "Skin sensation is essential for many manipulation and exploration tasks. To handle flexible materials like fabric and paper, we sense the pressure variation across the fingertip. In precision manipulation, perception of skin indentation reveals the relationship between the hand and the grasped tool. We perceive surface texture through the vibrations generated by stroking a finger over the surface. Tactile sensing is also the basis of complex perceptual tasks like medical palpation, where physicians locate hidden anatomical structures and evaluate tissue properties using their hands. Haptics is the study of the human sense of touch or the science of recreating touch by using computers and software. The word originates from the Greek word haptesthai, meaning to grasp or touch." (Haptics Community Web Page, http://haptic.mech.northwestern.edu/intro/tactile/).

Tactile or haptic feedback in this experiment is defined as vibration felt via the sense of touch from the mouse to the hand. This added stimulation, along with visual information, can be used to give the impression of actually feeling objects. It has been shown that, when tracing the shape of an object with the fingertip, the tactile information added to visual information increases the velocity in finger movements (Akamatsu, 1992). "This suggests that integration of visual and tactile information facilitates the manipulation of objects" (Akamatsu, Sato, & MacKenzie, 1994, p.73). Combining this tactile feedback with the mouse also has added advantages because the mouse has been found to be more effective at pointing tasks than joysticks or other devices (Card, English, & Burr, 1978). Previous studies have also indicated that the presence of tactile feedback reduced response times and increased the effective target area in mouse-positioning tasks. From this it can be concluded that in pointing tasks, multi-modal feedback is superior to visual feedback alone (Akamatsu & Sato, 1994).

Simple uses of tactile feedback have been implemented in applications such as shape encoding of manual controls in aircraft and other environments where lighting is an issue, or where concurrent tasks are being executed that require taking focus away from the controls themselves. Advances in technology have introduced only limited tactile feedback into mainstream interfaces through things like stick shakers for airplanes and video game systems, but the tactile mode of performance feedback has been relatively unexplored for utilization in applications requiring more complex discriminations. Target acquisition in military aircraft during combat and other applications requiring high precision and rapid performance with little room for error, are areas that could benefit significantly from the addition of frequency, magnitude and durational tactile feedback via a thumb joystick or other device.

There have been a few studies that have already been conducted in the area of target selection with the addition of tactile feedback (Akamatsu et al., 1994; Akamatsu & MacKenzie, 1996; Akamatsu et al., 1995; Engel, Goossens, & Haalma, 1994; Keyson, 1997). These studies have found that cursor-positioning times decrease when tactile feedback is introduced. There is also evidence that the addition of tactile information reduces response times in interactive systems (Nelson, McCandlish, & Douglas, 1990). Adding tactile feedback to the standard human computer interface could yield countless benefits resulting from the additional sensory information in cursor positioning. Typical PC users may benefit from this, but individuals who are visually or auditorily challenged, and operators of complex, highly automated systems such as aircraft and heavy machinery, could receive vital information via a tactile mode of feedback. The application where most people would be affected by the benefits of tactile feedback is expected in target selection tasks, which represents the most frequent utilization of a mouse. This benefit would have an even greater impact on the elderly population, because across the different segments of the population their target acquisition performance is improved the most (Keyson, 1997). It has also been reported that older computer user's position cursors much slower than younger users, and have great difficulty making correct movements to small targets (Worden, Walker, Bharat, & Hudson, 1997). This performance degradation in tracking and target acquisition abilities, resulting from the effects of aging on physical motor responses, could be offset to some degree, by tactile feedback. With the "baby-boomer" generation nearing the retirement age, the needs of the 60+ age group of the population is quickly becoming a market of interest to investors. The role computers play in helping older adults function in today's society is rapidly gaining more and more importance. This type of feedback can add value to any computer users experience, but would be highly valuable for older users in everyday tasks such as word processing or web navigation.

Immediate Feedback: In everyday tasks for anyone, physical motor responses result from sensory information that is gathered from the environment by the five senses, and can be classified into two categories; feedback and feedforward. Feedforward can be defined as everything that happens before a motor response starts, and feedback can be defined as all of the information available during and after a motor response. Feedback is another topic that has been extensively studied in the literature when it comes to information processing and human learning. In most studies on learning where some degree of immediate feedback is given on performance, there is almost always an improvement in performance. Immediate feedback allows a person to collect a base of knowledge that includes patterns and cues associated with what to do, and what not to do, to get a desired outcome. This base of knowledge is then drawn from, and built upon, in similar future experiences. These patterns and cues are all associated with varying degrees of correctness or incorrectness, and as this experience base grows, the immediate feedback can result in immediately adjusted performance. The immediately adjusted performance (or corrective actions taken) resulting from the immediate feedback, is justification for providing feedback as rapidly as possible. The longer feedback is delayed the greater the probability that important associations will not be made. The sooner a person is made aware of the situation, the sooner they will be able to alter it, and perform better. This is where the different modes of feedback from the different senses come into the picture. Having feedback from the different senses provides more opportunities for added information to be attached to these patterns or cues, resulting in better performance.

Mice: This study questions whether adding tactile feedback to the human-computer interface will affect human performance. To help answer this question, this experiment employed a mouse that provided tactile feedback. A mouse is defined as a device that when moved across a desktop or other surface, will produce a corresponding cursor movement on a computer screen. The first mouse was invented in 1964 by Douglas Engelbart, as an alternative to light pens and the other pointing devices available at that time. The movement of a mouse is detected mechanically or optically and is best suited for pointing and selection tasks. Card, English, and Burr, (1978) found that, out of the existing devices, the mouse was the best manual control device when both speed and accuracy were considered. The mouse has gone through many changes, but for all intents and purposes retains the same system level functionality as it did when it was first introduced.

Manual Control Theory: Manually controlling objects such as a mouse has historically been considered from the perspective of either skills or dynamic systems (Adams, 1961; Kelley, 1968). The skills approach involves analog motor behavior movement patterns reproduced from memory when there is little environmental uncertainty. Because these skills are being performed in a known environment it would be theoretically possible to perform them perfectly from trial to trial at a certain level of experience. Examples of this might be an assembly line worker doing a repetitive task, or a gymnast executing a maneuver in a routine. Once the skill has been developed there is little need to expend resources on processing feedback. This experiment will use the dynamic systems approach because it examines human abilities in controlling or tracking dynamic systems to make them conform to certain time-space trajectories in environmental uncertainty (Wickens, 1992). Many forms of manual control in human computer interaction are based on direct manipulation, from positioning a cursor with a mouse, to virtual reality. When humans perform manual skills they sometimes guide there hand through a coordinated time space trajectory, and other times just use their hands to guide the positioning of some other analog system or device. When discussing manual control of physical systems we move from discussing perceptual motor skills and motor behavior to tracking.

Tracking: Tracking involves executing correct moves at correct times. In some instances tracking is paced by the individual, and in others it is paced by some external force that the individual has no control over. The two basic types of tracking are pursuit tracking and compensatory tracking. Pursuit tracking is matching the output to the input and compensatory tracking is minimizing the error (when only the distance and direction of the error between the target and the tracking cursor is displayed) (Wickens, 1992). In pursuit tracking the independent movement of both the target and the cursor are presented and generally provides superior performance to compensatory tracking for two major reasons. First, pursuit tracking has an advantage over compensatory tracking in that when there is a changing command input, the stimulus-compatibility is greater. This means that if the command input moves left, a leftward movement is required for correction. In a compensatory display if the command input moves left it will be displayed as a right moving error and therefore the corrective actions required in the pursuit tracking display is more consistent with the operators tendency to want to move toward the source (Wickens, 1992). Pursuit tracking is also the superior method of tracking because the continuous immediate feedback participants are receiving is more easily parsed into what movement is resulting from the system output and what is resulting from the command input. This experiment employed a pursuit-tracking task in that the participant observed the moving input (the target), their own output (the cursor), and the distance between them (the error). In a tracking task the target is considered to be the input, or the path to follow. In effect the input specifies the output or control mechanism, which in this case will be the cursor. How well a person moves the control along the path or the input minus the output is the tracking error quantity, or the score. Some of the difficulties in real-world tracking situations include figuring out how a system will respond to guidance, what the desired trajectory of the system is, and how to perceive the information that is displayed. Another difficulty of tracking in the human-system interaction is that as a tracking task becomes more complicated and requires more corrections to make the system output match the command input, error increases and subsequently so does workload. The properties of the input determining the frequency at which corrections must be made is called the bandwidth of the input. In tracking tasks bandwidth is typically expressed in cycles per second (Hz). Humans do not perform well on tracking tasks with a bandwidth above about 1 Hz. A high bandwidth will keep an operator busy with feedback from different modes and manual control, but not in cognitive complexity. Cognitive complexity is affected by the order of the control system. The control order of a system is determined by direct relationships between a human's bodily movement and the movement of whatever is being controlled (Poulton, 1974). It refers to whether a change in the position of the control device by the human leads to a change in position, velocity, or acceleration of the system output. A system in which the position is changed is called a zero order control system. When velocity (rate of change of position) is added it is called a first order control system, and when acceleration (rate of change of velocity) is added it is called a second order control system. For example, just moving a computer mouse to position a cursor over a target on a display is a zero order control system, but if the target is moving then the goal is not only to change position, but also now match the velocity, so it becomes a first order control system.

Errors and subjective workload increase dramatically in systems with a second control order or higher. As the control order of a system increases, the lag of the system can also increase. "The lag is the amount by which an output trails an input. Lag is normally expressed in degrees of a cycle rather than in units of time. Thus, a half-second time delay will be a half-cycle lag at a frequency of one cycle per second (1Hz), but will be a quarter-cycle lag at a 0.5-Hz frequency (1 cycle/2seconds)"(Wickens, 1992, p. 486). For instance, controlling the speed of a car with the gas pedal depends on how far the pedal is depressed. The car only gradually reaches the speed that corresponds to the position of the pedal. In this example the lag is the time delay between the change in position of the pedal and the full corresponding change in speed (Poulton, 1974). The more lag a higher order control system has, the more sluggish and unstable it can become. An example of sluggishness would be for instance, when a cursor does not move when it is initially controlled, and stability is essentially a measure of the expected variance between the cursor and the target position relative to the observed variance. These require a human to use anticipation and prediction or control based on the future, not the present.

Gain or control-response ratio is another factor in tracking tasks. System gain is a ratio of the amplitude of the output to that of the input, or stated more simply, how much output is obtained from a given amount of input. In a high gain system such as the steering of a sports car that is highly responsive to inputs, a great deal of output is obtainable, where as the steering of a tractor would be significantly lower, because large inputs only produce small outputs. There is a tradeoff between the advantages of low gain (fine tuning) and high gain (rapid movement). Figuring out the optimum gain for a system depends on the task (Wickens, 1992). Real-world tracking is demonstrated in almost all aspects of vehicle control and energy control processes. Another example is direct manipulation in computer systems when continuous analog movement of a mouse or joystick is used to position cursors on display screens. Tracking performance is typically measured in terms of error calculated from different points accumulated over a tracking trial or trials. In this experiment the measurement of error was time off target.

Relationships between the input and output of systems can also be measured in other ways. A transfer function can be used to express a relationship in either a mathematical equation (change over time), or graphically, by showing a time varying output produced by a given time-varying input (Wickens, 1992). Another way that the difference between the current cursor location and the desired target has been depicted, is by characterizations of Fitts's Law.

Fitts Law: Fitts Law, established for visual pointing tasks, states that the movement time to acquire a target with a continuous linear direction, is a function of the target size and distance (Fitts, 1954). Fitts's equations are valuable because an increase in reaction time can be equated to a proportional increase in target size. "This is somewhat analogous to an increased efficiency in human performance in the task" (Akamatsu *et al.,* 1994, p.77). MacKenzie and Buxton (1992) present some examples of how this law can be applied in a two dimensional environment, since Fitts' Law deals with movement in only one dimension. This two-dimensional application of Fitts' law is important, because in graphical user interfaces, a mouse is manipulated in a two dimensional environment, obtaining a visual and kinesthetic (or body positioning) sense about the movement and position of both the cursor and the mouse. Fitts' Law also states that increasing the size of a target will reduce the total amount of time required to select it size (Fitts, 1954; MacKenzie & Buxton, 1992). It has also been found that people can physically respond faster to a somesthetic stimulus (perception of sensory stimuli from the skin) than to a visual stimulus (Nelson, McCanish, & Douglas, 1990). If we assume these to be true then we can also assume that the decrease in reaction time gained from the tactile feedback, effectively increases the size of the detectable target. Fitts' Law can also characterize the movement of a cursor toward a continuously moving target, but interest is more focused on minimizing the error than on the time required to reach the target. "Also, concern is less with the amplitude of the movement than it is with variables such as the frequency with which corrections must be made (the signal bandwidth), the complexity and lag of the dynamics of any system mediating between hand movements and cursor movement, and the manner in which feedback is displayed" (Salvendy, 1997, p. 120). A mouse provides more than one modality of sensory feedback and is therefore more like a persons interface with the real world, were they have multi-modal interaction with their environment. This study introduced multi-modal feedback via a mouse, to the information processing loop, to see what effect it really had on performance of a pursuit-tracking task.

Logitech® iFeel Mouse™: This experiment employed a Logitech iFeel mouse that uses a vibration generating motor to relay information to the hand. It was designed to simulate slip, impact, puncture, and different surface textures and materials when the cursor is moved over displayed objects like, icons, pull-down menus, hyperlinks, and dialog boxes. This type of technology can also be universally implemented without having to change existing software programs. Everything required for the Logitech iFeel mouse and other similar technologies to operate, is integrated into the hardware and software driver. In this experiment the participant received the tactile feedback or multi-modal feedback from the mouse vibrating when the cursor is over the target. This informed the participant that they were on target and tracking effectively. Delivering tactile feedback via a mouse should result in tasks that take less effort, are more accurate and are able to be completed faster. To demonstrate if this added tactile feedback actually causes a difference in performance participants were asked to complete a pursuit-tracking task using this mouse.

Summary

A regular mouse requires users to visually concentrate on the cursor as it moves around the screen. To do this they must first obviously, grasp the mouse. This act starts the flow of tactile information as well as kinesthetic information of movement and position from the muscles and joint receptors. This type of information is important, if for nothing else, just to confirm touching the object, but also as a supplement to visual information, or even as a substitute for it in its absence. In human computer interaction the human is presented information or objects on a display. These objects all have associated actions, structure, etc., and posses physical properties such as thickness, color, density, and contrast. Although a tactile sensation follows from the initial grasp of the mouse, its subsequent movement around the display produces no such sensation (Akamatsu et al., 1995). This means that information is being transferred to the computer tactually, but no information is being received back. "When a cursor enters an object, it figuratively 'touches' the object. When the cursor moves across a white background vs. a gray or patterned background, it passes over different 'textures'. Yet no sensory feedback (tactile or otherwise) is conveyed to the hand or fingers on the mouse" (Akamatsu et al., 1995, p.817). This omitted sensory information is not only a missed opportunity, but also a design flaw. The introduction of tactile feedback should better support human-machine communication in event-driven, information-rich domains. The Logitech iFeel mouse offers an added dimension, so that a user's performance is not diminished by depending too much on their visual mode of sensing. This facilitates multi-modal sensing like the real world. " When combined visual and tactile information is available, there is a rapid adaptation to a display-operation system as measured by certain movement characteristics and eye fixation. After adaptation, the operational movement becomes faster. If the operational movement is repeated, the movement will become even faster and the use of vision will be reduced" (Akamatsu, 1992). From this, it can be concluded that the most pronounced benefit from the addition of tactile feedback is that a tasks' visual demands are reduced; leaving that excesses capacity in visual resources open for other applications.

The application of tactile feedback technology is only recently being extensively explored. Some developing technologies that utilize tactile feedback include on-screen text to Braille readers, modeling in "digital clay", training in surgical procedures, telemedicine, training on clearing land mines, and vibrotactile displays of auditory information for the hearing impaired. These exciting new developments are just a few examples of the possible areas that could benefit from exploring the integration of tactile feedback. This study added the tactile feedback channel to the human computer interface through vibration of the mouse to more closely reflect a human's interaction with their environment in the real world and the feedback they receive from the various modes of sensing.

Statement of the Hypothesis

Based on the literature reviewed, it was hypothesized that pursuit-tracking performance will decrease as target movement speed increases. This study also tested the hypothesis that tactile feedback will improve performance in a pursuit-tracking task. An increase in time on target was expected for all experimental conditions where tactile feedback was present. It was also hypothesized that tactile feedback would affect performance differently as target movement speed increased.

METHOD

Participants

The participants in this experiment were 30 Embry-Riddle Aeronautical University undergraduate and graduate students between 19 and 42 years of age, with a mean age of 21.867. There were 20 male participants and 10 female participants. All participants were right handed, had 20/20 corrected or uncorrected vision, and were regular mice users.

Apparatus

This experiment utilized a Logitech iFeel optical mouse with a vibrating feature set at the highest magnitude provided, and a frequency of 125 Hz, to test the proposed hypothesis. The vibrating option of the Logitech iFeel optical mouse was enabled for the experimental conditions with tactile feedback, and then disabled for the experimental conditions with no tactile feedback. The software program for this experiment was custom built to record accuracy by measuring units of time off target in milliseconds, and total number of deviations. All data was collected on a standard IBM® PC™ at a sampling rate of once every 0.04s. Target size was 15mm (50 pixels) high by 15mm (50 pixels) wide on the 1024 x 768 resolution flat screen display.

Design

This experiment employed a pursuit-tracking task and was a within subjects, 2x3 full factorial design. The first independent variable in this experiment was type of feedback with two levels, (i.e. tactile feedback vs no tactile feedback). The second independent variable was speed of target at three different levels, (slow, medium, and fast). The 2 x 3 design yielded 6 different experimental conditions, and all participants were exposed to all conditions. The dependent variable in this experiment was time off target.

Procedure

Participants were brought into a room where they were tested for 20/20 corrected or uncorrected vision using an eye chart, and then seated at a work station where they were given a verbal briefing about the experiment (See Appendix A). Participants were then given a short questionnaire to fill out, and a consent form to read and sign (See Appendix B & C). A questionnaire provided by Peters (1998) containing 12 questions (See in Appendix B "*Annett's (1995) 12-item Handedness Questionnaire*") was also filled out by all participants to determine handedness. A 3 point scale was used: 1 = left hand; 2 = either hand; 3 = right hand, for the determination of handedness. Each participant's average in the test determined if he/she was right-handed and could be tested. If the participant had an average <24, then the participant was considered left-handed and eliminated. If the participant had an average >24, the participant would proceed with the experiment. Participants were then assigned to a randomly generated order of presentation for the six experimental conditions to protect against practice and order effects. Order of presentation of experimental condition was determined by a combination of independent variables that was each assigned a number 1, 2, 3, 4, 5, or 6 (Table 1).

Table 1. Experimental Conditions Matrix.

	Fast 1	**Medium 2**	**Slow 3**
Tactile Feedback Enabled 1	1	2	3
Tactile Feedback Disabled 0	4	5	6

Participants were then given a chance to practice tracking targets for 30 seconds, with tactile feedback and without tactile feedback. Participants were instructed to track a randomly moving target for 2 minutes as accurately as possible over the six trials. All participants went through all six target-tracking trials at three different speeds in a random order of presentation. Each participant tracked targets at each speed with tactile feedback and without tactile feedback. A trial started when the participant moved the cursor over and clicked on a small box in the center bottom portion of the screen. A target then appeared and began to move around the screen. Three starting locations for targets were randomly selected, and three movement patterns were randomly generated. One was assigned to each speed so all target starting locations and patterns remained constant within each speed. The experimenter was present throughout all of the trials and asked each participant to turn around between each trial so the speed of the target and the type of the feedback could be alternated without the participants' knowledge. At the end of each trial a message appeared on the screen to notify the participant that the trial had ended, and to wait for the administrator.

RESULTS

Time off target data from this experiment was analyzed using a repeated measures analysis of variance (ANOVA) including Mauchly's test of sphericity. If the sphericity test was rejected ($\alpha < .05$), the adjusted Greenhouse-Geisser estimate was used to adjust the numerator and denominator degrees of freedom. The ANOVA yielded significant main effects for both the speed and feedback factors, but no significant interaction between speed and feedback was obtained (Appendix H (Table 2) and Appendix I (Table 3). Time off target was significantly different for fast, medium, and slow speeds when tactile feedback was present (Figure 3).

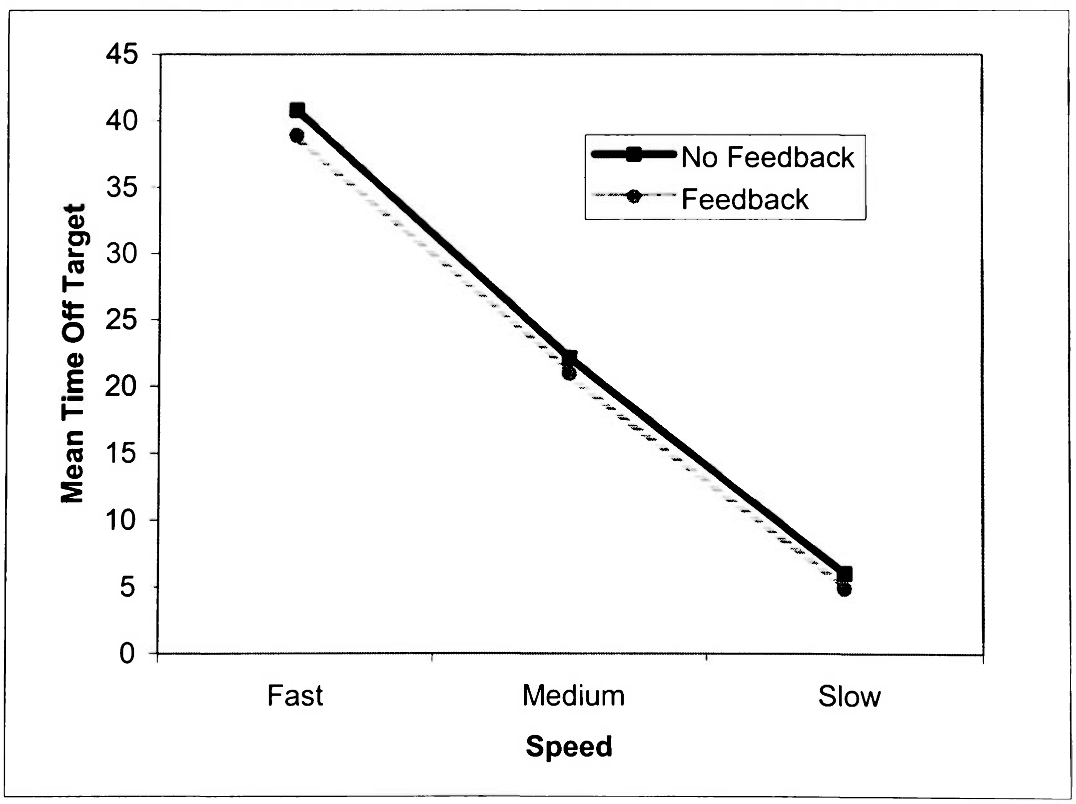

Figure 3. Mean time off target for each experimental condition

Speed

Muachly's test of sphericity for the speed factor showed a violation of the sphericity assumption. The adjusted Greenhouse-Geisser estimate was used to adjust the significance level of the *F* value and correct for positive bias. The ANOVA of the speed factor showed a significant main effect $F(1.308,37.934) = 582.949$, $\alpha < .0001$. The hypothesis that pursuit-tracking performance will decrease as target movement speed increases was supported (Figure 4). An eta squared of .953 was obtained, indicating that the speed factor accounted for 95.3% of the variability in the means.

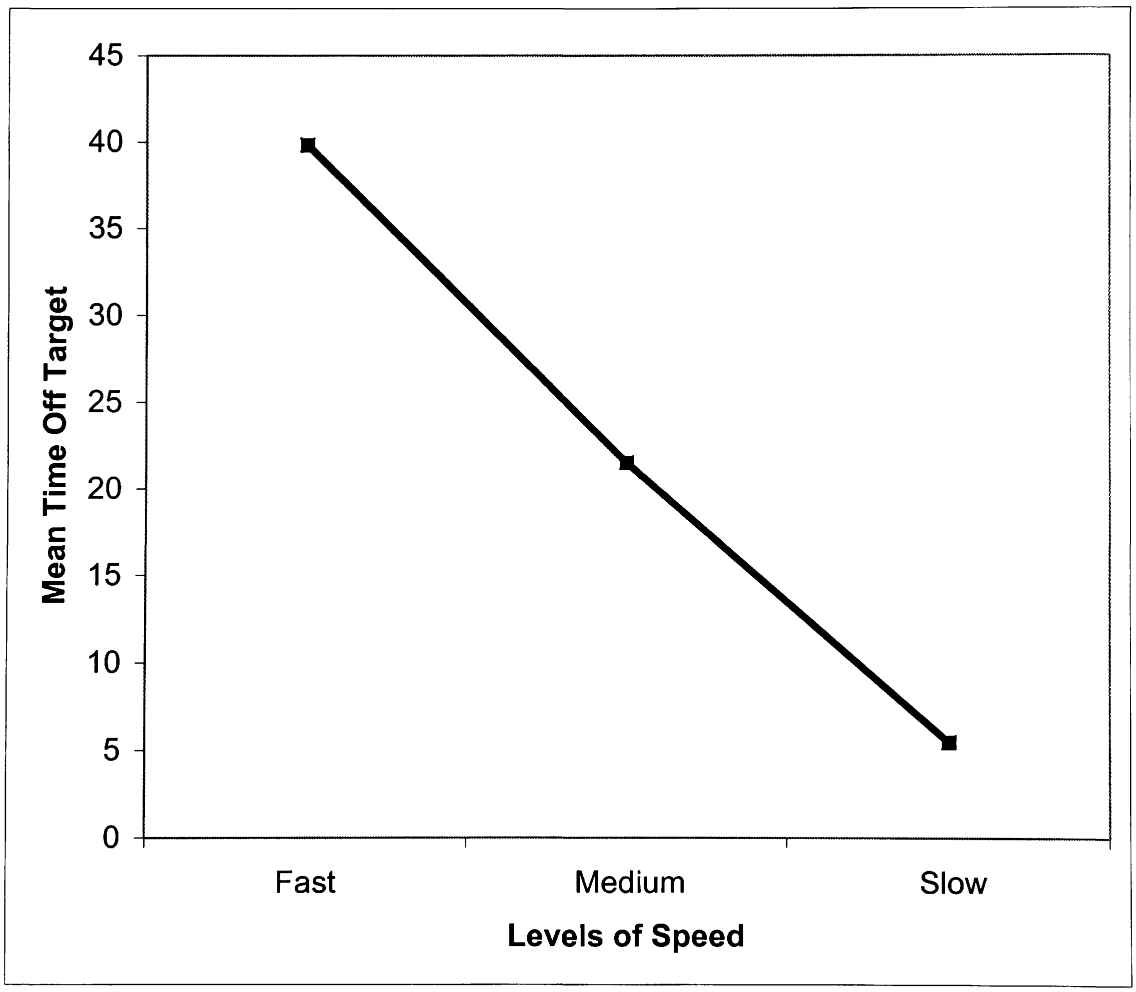

Figure 4. Mean time off target for speed factor

Feedback

The ANOVA of the feedback factor showed a significant main effect $F(1,29) = 88.873$, $\alpha < .0001$. The hypothesis that tactile feedback will increase performance in a pursuit-tracking task was supported (Figure 5). An eta squared of .351 was obtained, indicating that the feedback factor accounted for 35.1% of the variability in the means.

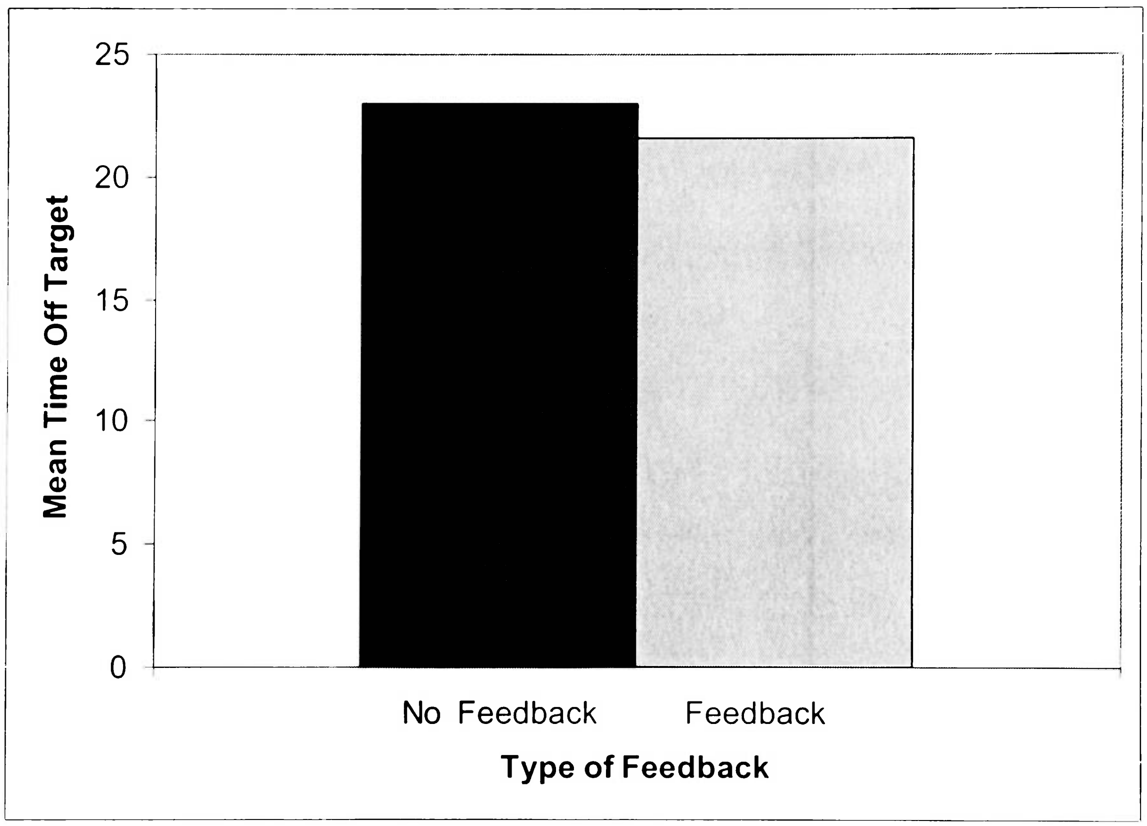

Figure 5. Mean time off target for feedback factor

Interaction (Speed x Feedback)

There was no interaction between the speed and feedback factors (Figure 3). Tactile feedback has an effect on performance regardless of speed. The hypothesis that tactile feedback would affect performance differently as speed varied was not supported.

DISCUSSION

The results from this experiment reveal that processing of information, via tactile feedback, can improve performance, therefore demonstrating that multimodal feedback is superior to a single mode of feedback. This application of tactile feedback resulted in a 6% increase in pursuit tracking performance. Although the performance increase is small, it could be significantly beneficial in situations or applications requiring more complex discriminations, such as tasks that are time critical or where safety is an issue. The medical community is also one that could see advantages through applications of this technology in training and simulation. For example, before doctors perform brain surgery, or separate conjoined twins the surgeon can first digitally map the brain, or twins, and then project that image into a three dimensional space. The surgeon could then practice the operation with the addition of tactile feedback to improve their performance in the actual operation. Another example might be in the military arena, where bombs and missiles are now remotely flown, and can be guided down chimneys or into bridge pylons. These are just a couple examples of where a 6% increase in performance might actually save a human life. A more direct application would be in aiding the compensatory tracking of an ILS (instrument landing system) approach in aircraft. If the addition of tactile feedback could reduce approach and landing times by as little as a few minutes, airline operators might be interested in a 6% improvement in performance just to save on fuel costs alone. Real-world tracking is demonstrated in almost all aspects of vehicle control and energy control processes. Redundant and multi-modal cues could also be especially useful in applications that primarily rely on one mode of information transfer, such as aviation, where visio-spatial resources are relied on heavily. In more practical applications, tactile feedback could help reduce visual demands in tasks like object selection on screens that contain multiple targets, or text correction of characters, words, or lines from typing errors. Even efficiency and effectiveness in selecting common visual objects like pull-down menus, links, and buttons should be improved.

Typical PC users may see benefits from this type of technology, but individuals who are visually or auditorily challenged, and operators of complex highly automated systems such as aircraft and heavy machinery, could receive vital information via a tactile mode of feedback. The most widely used input device today is the mouse. The mechanisms required to convey tactile information to the human are inexpensive to manufacture. Advances in miniaturization and fine tune controlling of frequency, magnitude, and duration in haptic devices, has made them more practical and acceptable in operational settings. Positioning a cursor with a standard mouse requires visual concentration. This experiment has demonstrated that using a mouse that distributes presentation of information across modalities, increases performance.

Akamatsu et al., 1994; Akamatsu & MacKenzie, 1996; Akamatsu et al., 1995; Engel, Goossens, & Haalma, 1994; and Keyson, 1997 all conducted studies in the area of target selection with the addition of tactile feedback. This is most likely the application where most people would be affected by the benefits of tactile feedback because target selection represents the most frequent utilization of a mouse. This preliminary investigation suggests that information processing efficiency is increased when multi-modal feedback is offered. Although this experiment was consistent with previous research in finding a significant difference in performance, more research is needed in utilizing this type of technology in situations or applications requiring more complex discriminations.

There are many prospective applications of this technology both within, and outside of the human-computer interface, that should be examined. Further investigations into the benefits of parallel processing of information and multi-modal feedback should incorporate the other senses to see if similar improvements in performance exist. Future experiments might also include a secondary visual monitoring and recall task, to see if the multi-modal feedback conditions resulted in an even greater increase in efficiency of information processing and subsequent performance. This would lend further support to the theory that adding tactile feedback reduces tasks' visual demands, leaving that excess capacity in visual resources open for other applications.

Another area of interest might be to have tactile feedback provided when the cursor is not on target, as opposed to when it is on target to see if a difference exists between positive and negative feedback. Further research into limits of simultaneous perception of visual, olfactory, auditory and tactile information should be pursued. This research should also be expanded to other machine interfaces and other points on the body for the administration of tactile feedback. Additional inquiries should also be pursued into the extent to which tactile feedback can benefit the visually impaired, the elderly, and even everyday people with less than perfect vision. Other frequencies and magnitudes should also be studied to establish a range of effective combinations, or even an optimal combination. It will also be important to study the effects of different methods of delivering tactile feedback in settings like cockpits, where environmental and situational information is already being conveyed tactually. In situations like this vibration and kinesthetic feedback could interfere with or even mask the transmission of tactile stimuli, and vice-versa.

CONCLUSIONS

Adding tactile feedback to the human computer interface could result in improvements in efficiency and effectiveness in some applications. Advances in miniaturization and fine-tune controlling of frequency, and magnitude in haptic devices, has made them more acceptable for operational settings. Whenever and wherever, warranted practical and possible, multimodal feedback should be offered. Incorporating tactile feedback into the human-computer interface can increase information-processing efficiency by facilitating multi-modal sensing like the real world. Parallel processing of information via the visual and tactile senses was shown to produce better performance than using the visual sense alone. This study demonstrates the added value of considering the different sensory modalities in user interface design, and the type of benefits it can produce.

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Appendix A

BRIEFING

"Effect of tactile feedback on performance"

Hello, My name is Darren Wilson and I am a graduate student in the Human Factors and Systems Department. Today you will be participating in an experiment where you will be asked to track a target on a computer screen, with a cursor, using a mouse. The target is a small white square and the cursor is a standard arrow. Your objective in this experiment is to keep the tip of the arrow inside the white box at all times. In half of the trials, when you are over the target or when the tip of the arrow is inside the white square the mouse will vibrate to notify you that you a effectively tracking the target. The experiment will begin when you position the cursor over, and click on the small box in the center bottom portion of the screen. The target (white square) will then appear in a random location on the screen and begin to move around the screen in a random pattern. You will first be given a 30 second practice trial to track targets with tactile feedback and without tactile feedback. You will then go through six, two-minute trials. You will be notified that each trial has ended by a message that will appear in the center of the screen that says the trial has ended and to wait for the administrator. Remember, please do your very best to keep the tip of the arrow inside the white box, and notify me when each trial is over. Thank you very much for volunteering and good luck.

Appendix B

QUESTIONNAIRE

"Effect of tactile feedback on performance"

1. Name ______________________________ 2. Age _____ 3. Gender M / F

4. How often do you use a mouse? ___________________________________

5. Are you left handed or right handed? Left Handed Right Handed

6. Do you have 20/20 correctable vision? Yes No

Appendix C

CONSENT FORM

"Effect of tactile feedback on performance"

Conducted by Darren Wilson
Advisor: Dr. John Wise
Embry-Riddle Aeronautical University
600 South Clyde Morris Blvd.
Daytona Beach, FL 32114

The experiment you are about to participate in is designed to investigate the relationship between tactile feedback and performance. In this experiment you will be required to track a moving icon with a mouse in a standard PC setup. The experiment will consist of one, 20-minute session and there are no known risks associated with this experiment.

Any personal information collected during this experiment such as your name and age will not be reported and remain confidential.

Your participation is completely voluntary and you are free to withdraw from the experiment at any time.

Thank you for your participation and feel free to contact me at (904) 453-5422 with any questions you might have.

I acknowledge that I have read the above text, been informed of, and fully understand the nature and purpose of this study. I freely consent to participate by signature of this document.

Participant's Printed Name: ______________________

Participant's Signature: __________________________ Date: ___________

Appendix D

HANDEDNESS QUESTIONNAIRE

"Effect of tactile feedback on performance"

Name:____
Date of the Tests:____

Annett's (1995) Handedness Questionnaire from Peters, 1998):

Please indicate your preferences in the use of hands by putting the value in the preference column. Use 1= left hand; 2=either hand; 3=right hand.
Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

List of items:	**Preference:**
1. write	
2. brush teeth	
3. throw ball	
4. hold tennis racquet	
5. hammer in a nail, hand that holds the hammer	
6. use scissors	
7. strike match, hand that strikes match	
8. thread needle (which hand moves)	
9. sweep with broom (lower hand when sweeping to the right)*	
10. shovel with large shovel (hand that pushes the shovel)	
11. which hand deals cards	
12. which hand unscrews jar lid (small and light jar)*	

***Do you suffer from any physical or other handicap that might influence your answers to these questions? Yes_____ No______ Not sure______*

Total: ________

Appendix E

DEBRIEFING

"Effect of tactile feedback on performance"

Thank you for taking the time to participate in this study. The results of this study will be available in the Embry-Riddle Aeronautical University library under either the author's name: Darren P. Wilson, or the study's title:

EFFECT OF TACTILE FEEDBACK ON PERFORMANCE

If you need any additional information or would like to obtain a copy of this study you can contact me via e-mail at wilsonda@db.erau.edu. Again, thank you for participating and feel free to contact me at any time if you have any questions.

Appendix F

Software Requirements Specification

"Effect of tactile feedback on performance"

1.0 - Purpose

The purpose of this Software Requirements Specification is to clarify the necessary requirements for the software program that was created by Matt Armstrong. This software was used to investigate the effect of tactile feedback on performance. This document gives the high level functional requirements for the project in a fashion, which will facilitate any future users of this software, and developers or designers of similar software or upgrades to this software.

2.0 - Problem Statement

The project software will provide a precise and accurate record of any participant's involvement in the demonstration. The software currently available on today's market is ineffective at providing a sufficient quantity of high quality data to discern whether or not tactile feedback has an effect on performance. The purpose of the software is to improve upon all the shortcomings of pursuit tracking data collection methods, and present the user with quality data in a usable medium that facilitates statistical analyses.

3.0 - Functional Requirements

3.1 – Administrator Control Dialogue Screen:

The primary administrator interface shall consist of one main dialogue window.

3.1.1 – The main screen shall contain all of the control functionality.

3.1.2 – The main screen shall have a window to input a participants I.D..

3.1.3 – The main screen shall have a way to select one of the three target speeds.

3.1.4 – The main screen shall have an option to enable and disable the tactile feedback of the mouse.

3.1.5 – The main screen shall have a way to adjust the frequency of the vibration of the mouse.

3.1.6 – The main screen shall reset between trials.

3.1.7 – The main window shall be used to set up the conditions for each trial.

3.2 – User Display:

The primary user interface will consist of a full screen display.

3.2.1 – The display will have an activation button.

3.2.3 – The display shall have a randomly moving target.

3.2.4 – The display shall be black.

3.2.5 – The target on the display shall be white.

3.2.6 – At the end of each trial dialogue shall appear to notify the participant that the trial has ended.

3.3 - Data Collection :

The software shall record multiple sets of data in different forms from each participant's trials.

3.3.1 – Data shall be collected on which speed the target is traveling during a trial.

3.3.2 – Data shall be collected on whether or not tactile feedback was present.

3.3.3 – Data shall be collected on whether or not the cursor was over the target.

3.3.4 – Data shall be collected on time during a trial that a deviation occurred.

3.3.5 – Data shall be collected on how long a deviation occurred for.

3.3.6 – Data shall be collected on the maximum distance a cursor deviated from the target.

3.4 – Data Output:

The data shall be output into an easily usable format.

3.4.1 – Data shall be but into organized easily readable format.

3.4.2 – Data organization shall facilitate analyses.

3.4.3 – Data shall be output in columns.

Appendix G

Software User Manual

"Effect of tactile feedback on performance"

This software program was developed in Visual C++ using MFC (Microsoft Foundation Classes). The application is made up of two dialog boxes. The first is a setup dialog where you choose the parameters for the trial and the second is a large black dialog that the trial is run on. The white square or target is drawn directly onto the device context for the dialog box and movement its movement is controlled by the timer functionality provided by MFC. The square moves every 0.04 seconds (25 Hz) and the position of the cursor relative to the target is calculated at the same rate. The tactile feedback functionality uses the IFC (Immersion Foundation Classes) library from the Immersion Corporation. Total time spent in research and development for this software program was approximately 30 hours total.

Administrator Functionality

Step #1
First click the left mouse button over the 'testMouse' icon shown here.

Step #2
Next, enter the participant's identification in the window next to Subject Name. (See Figure 6)

Step #3
Then select the desired speed for that trial.

Step #4
If you would like to run the trial with the addition of tactile feedback from the mouse and the box next to Enable is not already checked, simply click the left mouse button over the box to enable the tactile feedback. If you would like to run the trial without tactile feedback, make sure the box next to Enable is not checked and skip to Step #5.

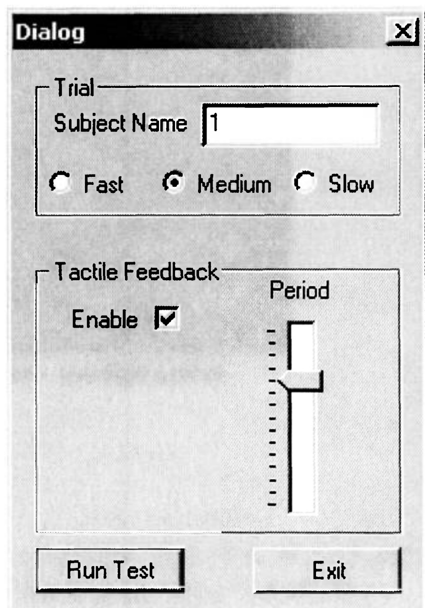

Figure 6. Administrator Control Dialogue Box - the setup dialog where you choose the parameters for a trial.

Next, click and hold the left mouse button down over the slide bar under Period. Move the slide bar up to increase the intensity of vibration and down to decrease the intensity of vibration.

Step #5
Finally, to start the trial click the left mouse button on Run Test or to exit the setup click the left mouse button on Exit.

User/Participant Functionality

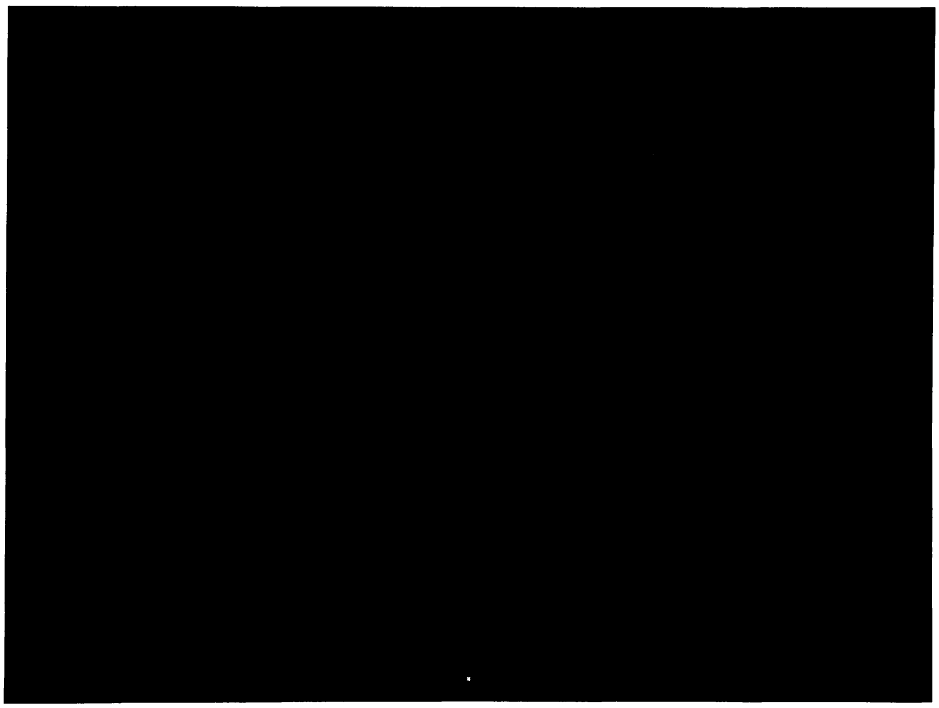

Figure 7. User Display Window with Activation Button – the first screen user sees before starting the trial.

Step #1
To start the experiment, simply position the tip of the cursor over and click the left mouse button on the small box in the center bottom portion of the screen. (See Figure 7)

Step #2
Now that the trial has started a white box will appear and begin to move randomly around the screen (See Figure 8). Position the tip of the cursor inside the white box and keep there by adjusting the position of the mouse.

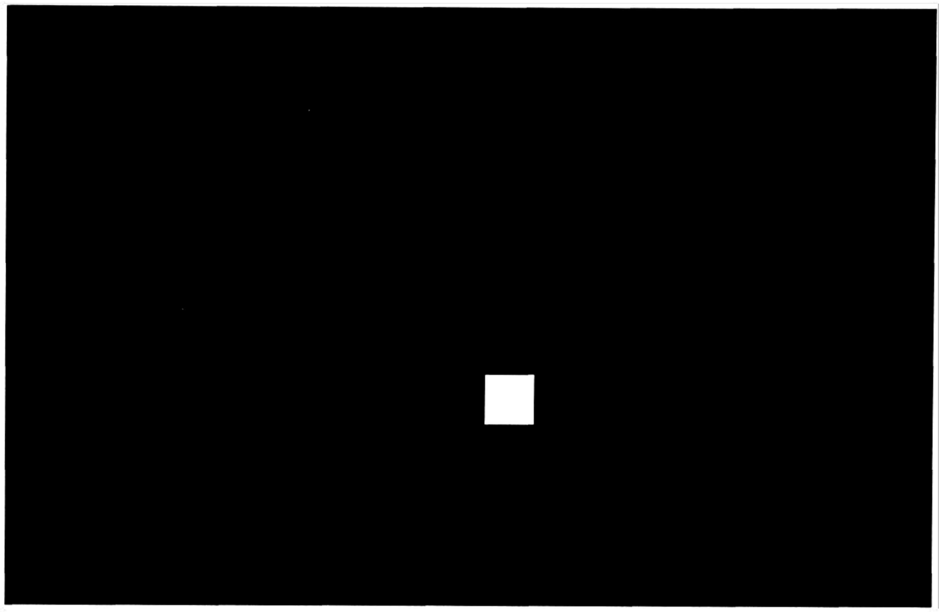

Figure 8. User Display Window During Trial – the display users see during a trial.

Step #3
When the trial ends a message will appear saying 'Trial Ended, Please Wait for Administrator' (See Figure 9). Notify the Administrator that the trial has ended.

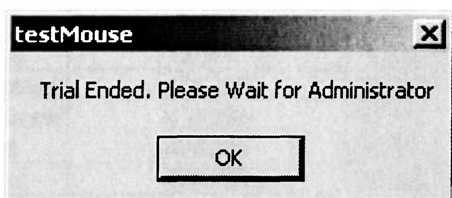

Figure 9. Trial End Notification Window.

Appendix H

Source Table

"Effect of tactile feedback on performance"

Table 2. Source Table

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Power
SPEED	Sphericity Assumed	35520.890	2.000	17760.445	582.949	0.000	0 953	1
	Greenhouse-Geisser	35520.890	1 308	27155.134	582.949	0.000	0 953	1
	Huynh-Feldt	35520.890	1.345	26412.037	582.949	0.000	0 953	1
	Lower-bound	35520.890	1.000	35520.890	582.949	0.000	0 953	1
Error(SPEED)	Sphericity Assumed	1767.059	58.000	30.467				
	Greenhouse-Geisser	1767.059	37.934	46.582				
	Huynh-Feldt	1767.059	39.001	45.308				
	Lower-bound	1767.059	29.000	60.933				
FEEDBACK	Sphericity Assumed	88.873	1.000	88.873	15.704	0.000	0.351	0 969
	Greenhouse-Geisser	88.873	1.000	88.873	15.704	0.000	0.351	0.969
	Huynh-Feldt	88.873	1.000	88.873	15.704	0.000	0.351	0 969
	Lower-bound	88.873	1.000	88.873	15.704	0.000	0 351	0.969
Error(FEEDBACK)	Sphericity Assumed	164.122	29.000	5.659				
	Greenhouse-Geisser	164.122	29.000	5.659				
	Huynh-Feldt	164.122	29.000	5 659				
	Lower-bound	164 122	29.000	5.659				
SPEED * FEEDBACK	Sphericity Assumed	5.187	2.000	2.594	0.317	0.729	0.0108	0 0982
	Greenhouse-Geisser	5.187	1.796	2.889	0.317	0.706	0.0108	0.0957
	Huynh-Feldt	5 187	1 907	2.721	0.317	0.719	0.0108	0.0971
	Lower-bound	5.187	1.000	5 187	0.317	0.578	0.0108	0.0846
Error (SPEED*FEEDBACK)	Sphericity Assumed	474.298	58.000	8 178				
	Greenhouse-Geisser	474.298	52.072	9.109				
	Huynh-Feldt	474.298	55.291	8.578				
	Lower-bound	474.298	29.000	16.355				

Appendix I

Descriptive Statistics

"Effect of tactile feedback on performance"

Table 3. Descriptive Statistics

Experimental Condition	Mean	Standard Deviation	N
Fast No Feedback	40.7787	9.3706	30
Fast Feedback	38.8933	9.4897	30
Medium No Feedback	22.1093	7.1745	30
Medium Feedback	20.9333	6.624	30
Slow No Feedback	6.028	3.0871	30
Slow Feedback	4.8733	1.9554	30